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Cascade Decays in the NMSSM [1]

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Abstract

We study unconventional signatures of the NMSSM (the MSSM with an additional gauge singlet) with a singlino LSP. Compared to sparticle production processes in the MSSM, these consist in additional cascades (one or two additional l^+l^-, $\tau^+\tau^-$ or $b\bar{b}$ pairs or photons), possibly with macroscopically displaced vertices with distances varying from millimeters to several meters.

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Definition of the Model:

The NMSSM (Next-to-minimal SSM, or (M+1)SSM) is defined by the addition of a gauge singlet superfield S to the MSSM. The superpotential W is scale invariant, i.e. there is no μ-term. Instead, two Yukawa couplings λ and κ appear in W. Apart from the standard quark and lepton Yukawa couplings, W is given by

$$W = \lambda H_1 H_2 S + \frac{1}{3}\kappa S^3 + \dots \tag{1}$$

and the corresponding trilinear couplings A_λ and A_κ are added to the soft susy breaking terms. The vev of S generates an effective μ-term with $\mu = \lambda\langle S\rangle$.

The constraint NMSSM (CNMSSM) [1] is defined by universal soft susy breaking gaugino masses M_0, scalar masses m_0^2 and trilinear couplings A_0 at the GUT scale, and a number of phenomenological constraints:
- Consistency of the low energy spectrum and couplings with negative Higgs and sparticle searches.
- In the Higgs sector, the minimum of the effective potential with $\langle H_1\rangle$ and $\langle H_2\rangle \neq 0$ has to be deeper than any minimum with $\langle H_1\rangle$ and/or $\langle H_2\rangle = 0$. Charge and colour breaking minima induced by trilinear couplings have to be absent. (However, deeper charge and colour breaking minima in "UFB" directions are allowed, since the decay rate of the physical vacuum into these minima is usually large compared to the age of the universe [2].)

Cosmological constraints as the correct amount of dark matter are not imposed at present. (A possible domain wall problem due to the discrete Z_3 symmetry of the model is assumed to be solved by, e.g., embedding the Z_3 symmetry into a $U(1)$ gauge symmetry at M_{GUT}, or by adding non-renormalisable interactions which break the Z_3 symmetry without spoiling the quantum stability [3].)

The number of free parameters of the CNMSSM, ($M_{1/2}$, m_0, A_0, λ, κ + standard Yukawa couplings), is the same as in the CMSSM ($M_{1/2}$, m_0, A_0, μ, $B + idem$). The new physical states in the CNMSSM are one additional neutral Higgs scalar and Higgs pseudoscalar, respectively, and one additional neutralino. In general these states mix with the corresponding ones of the MSSM with a mixing angle proportional to the Yukawa coupling λ. However, in the CNMSSM λ turns out to be quite small, $\lambda \lesssim 0.1$ (and $\lambda \ll 1$ for most

allowed points in the parameter space) [1]. Thus the new physical states are generally almost pure gauge singlets with very small couplings to the standard sector.

Phenomenology of the CNMSSM:

The new states in the Higgs sector can be very light, a few GeV or less, depending on λ [4]. Due to their small couplings to the Z boson they will escape detection at LEP and elsewhere, i.e. the lightest "visible" Higgs boson is possibly the next-to-lightest Higgs of the NMSSM. The upper limits on the mass of this visible Higgs boson (and its couplings) are, on the other hand, very close to the ones of the MSSM, i.e. $\lesssim 140$ GeV depending on the stop masses [4].

The phenomenology of sparticle production in the CNMSSM can differ considerably from the MSSM, depending on the mass of the additional state $\tilde{S}$ in the neutralino sector: If the $\tilde{S}$ is not the LSP, it will hardly be produced, and all sparticle decays proceed as in the MSSM with a LSP in the final state. If, on the other hand, the $\tilde{S}$ is the LSP, the sparticle decays will proceed differently: First, the sparticles will decay into the NLSP, because the couplings to the $\tilde{S}$ are too small. Only then the NLSP will realize that it is not the true LSP, and decay into the $\tilde{S}$ plus an additional cascade.

The condition for a singlino LSP scenario can be expressed relatively easily in terms of the bare parameters of the CNMSSM: Within the allowed parameter space of the CNMSSM, the lightest non-singlet neutralino is essentially a bino $\tilde{B}$. Since the masses of $\tilde{S}$ and $\tilde{B}$ are proportional to A_0 and $M_{1/2}$, respectively, one finds, to a good approximation, that the $\tilde{S}$ is the true LSP if the bare susy breaking parameters satisfy $|A_0| \lesssim 0.4 M_{1/2}$. Since $A_0^2 \gtrsim 9 m_0^2$ is also a necessary condition within the CNMSSM, the singlino LSP scenario corresponds essentially to the case where the gaugino masses are the dominant soft susy breaking terms.

Note, however, that the $\tilde{B}$ is not necessarily the NLSP in this case: Possibly the lightest stau $\tilde{\tau}_1$ is lighter than the $\tilde{B}$, since the lightest stau can be considerably lighter than the sleptons of the first two generations. Nevertheless, most sparticle decays will proceed via the $\tilde{B} \to \tilde{S} + \dots$ transition, which will give rise to additional cascades with respect to decays in the MSSM. The properties of this cascade have been analysed in [5], and in the following we will briefly discuss the branching ratios and the $\tilde{B}$ life times in the different

parameter regimes:

a) $\tilde{B} \to \tilde{S}\nu\bar{\nu}$: This invisible process is mediated dominantly by sneutrino exchange. Since the sneutrino mass, as the mass of $\tilde{B}$, is essentially fixed by $M_{1/2}$ [5], the associated branching ratio varies in a predictable way with $M_{\tilde{B}}$: It can become up to 90% for $M_{\tilde{B}} \sim 30$ GeV, but decreases with $M_{\tilde{B}}$ and is maximally 10% for $M_{\tilde{B}} \gtrsim 65$ GeV.

b) $\tilde{B} \to \tilde{S}l^+l^-$: This process is mediated dominantly by the exchange of a charged slepton in the s-channel. If the lightest stau $\tilde{\tau}_1$ is considerably lighter than the sleptons of the first two generations, the percentage of taus among the charged leptons can well exceed $\frac{1}{3}$. If $\tilde{\tau}_1$ is lighter than $\tilde{B}$, it is produced on-shell, and the process becomes $\tilde{B} \to \tilde{\tau}_1\tau \to \tilde{S}\tau^+\tau^-$. Hence we can have up to 100% taus among the charged leptons and the branching ratio of this channel can become up to 100%.

c) $\tilde{B} \to \tilde{S}S$: This two-body decay is kinematically allowed if both $\tilde{S}$ and S are sufficiently light. (A light S is not excluded by Higgs searches at LEP1, if its coupling to the Z is too small [4].) However, the coupling $\tilde{B}\tilde{S}S$ is proportional to λ^2, whereas the couplings appearing in the decays a) and b) are only of $O(\lambda)$. Thus this decay can only be important for λ not too small. In [5], we found that its branching ratio can become up to 100% in a window $10^{-3} \lesssim \lambda \lesssim 10^{-2}$. Of course, S will decay immediately into $b\bar{b}$ or $\tau^+\tau^-$, depending on its mass. (If the branching ratio $Br(\tilde{B} \to \tilde{S}S)$ is substantial, S is never lighter than ~ 5 GeV.) If the singlet is heavy enough, its $b\bar{b}$ decay gives rise to 2 jets with B mesons, which are easily detected with b-tagging. In any case, the invariant mass of the $b\bar{b}$ or the $\tau^+\tau^-$ system would be peaked at M_S, making this signature easy to search for.

d) $\tilde{B} \to \tilde{S}\gamma$: This branching ratio can be important if the mass difference $\Delta M = M_{\tilde{B}} - M_{\tilde{S}}$ is small ($\lesssim 5$ GeV).

Further possible final states like $\tilde{B} \to \tilde{S}q\bar{q}$ via Z exchange have always branching ratios below 10%. (The two-body decay $\tilde{B} \to \tilde{S}Z$ is never important, even if ΔM is larger than M_Z: In this region of the parameter space $\tilde{\tau}_1$ is always the NLSP, and thus the channel $\tilde{B} \to \tilde{\tau}_1\tau$ is always prefered.)

The $\tilde{B}$ life time depends strongly on the Yukawa coupling λ, since the mixing of the singlino $\tilde{S}$ with gauginos and higgsinos is proportional to λ. Hence, for small λ (or a small mass difference ΔM) the $\tilde{B}$ can be so long lived that it decays only after a macroscopic lenght of flight $l_{\tilde{B}}$. An approximate

formula for $l_{\tilde{B}}$ (in meters) is given by

$$l_{\tilde{B}}[m] \simeq 2 \cdot 10^{-10} \frac{1}{\lambda^2 \cdot M_{\tilde{B}}[GeV]} \ , \tag{2}$$

and $l_{\tilde{B}}$ becomes > 1 mm for $\lambda \lesssim 6 \cdot 10^{-5}$.

To summarize, the following unconventional signatures are possible within the CNMSSM, compared to the MSSM:
a) additional cascades attached to the original vertex (but still missing energy and momentum): one or two additional l^+l^-, $\tau^+\tau^-$ or $b\bar{b}$ pairs or photons, with the corresponding branching ratios depending on the parameters of the model.
b) one or two additional l^+l^- or $\tau^+\tau^-$ pairs or photons with macroscopically displaced vertices, with distances varying from millimeters to several meters. These displaced vertices do not point towards the interaction point, since an additional invisible particle is produced.

More details on the allowed branching ratios and life times can be found in [5], applications to sparticle production processes et LEP 2 are published in [6], and differential (spin averaged) cross sections of the $\tilde{B} \to \tilde{S}$ decay are available upon request.

References

[1] U. Ellwanger, M. Rausch de Traubenberg, C. Savoy, Nucl. Phys. **B 492** (1997) 21
[2] U. Ellwanger, C. Hugonie, "Constraints from Charge and Colour Breaking Minima in the (M+1)SSM", in preparation
[3] C. Panagiotakopoulos, K. Tamvakis, hep-ph/9809475
    S.A. Abel, *Nucl. Phys.* **B 480** (1996) 55
[4] U. Ellwanger, M. Rausch de Traubenberg, C. Savoy, Z. Phys. **C 67** (1995) 665
[5] U. Ellwanger, C. Hugonie, Eur. Phys. J. **C5** (1998) 723
[6] U. Ellwanger, C. Hugonie, hep-ph/9812427